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After the Earthquake in the Low-Altitude Economy, Drones Deliver Relief Supplies

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Abstract

The low-altitude economy is developing rapidly, and UAV post-earthquake rescue is helpful to improve the emergency response ability of post-earthquake rescue. Due to road damage, complex terrain, and uncertainty of meteorological conditions, ground rescue in the post-earthquake disaster area often cannot carry out full coverage of the earthquake-stricken area with high efficiency, while UAV has the characteristics of flexibility, dynamic real-time information, and intelligence, which is conducive to the application of post-earthquake rescue. The low-altitude economy has become a worldwide development trend, among which the development of low-altitude economy including UAM (UrbanAirMobility, urban air transportation), regional aviation logistics, and drones has become an important part of the global trend, and a variety of UAV application services and application scenarios such as logistics, environmental monitoring, and emergency rescue have been developed. Based on the background of low-altitude economic development, this paper discusses the application of UAV post-earthquake rescue, and analyzes the technical problems such as UAV post-earthquake rescue application technology, rescue material aerial throwing application, UAV route modeling airspace management application, etc., in order to play a positive role in post-earthquake rescue emergency response.

Keywords

Low-altitude Economy; Drone; Post-earthquake Rescue; Route Modeling.

1. Introduction

The application of drones has broad prospects, and the rise of the "low-altitude economy" will also open a new chapter in the application of drones. The low-altitude economy is defined as "an economic form of transportation, testing, logistics, and other activities such as transportation, inspection, and logistics carried out by unmanned aerial vehicles and aircraft in low-altitude space below 3,000 meters." With the increasing maturity of UAV technology and the gradual opening of low-altitude control policies, the low-altitude economy will bring new impetus to the upgrading of the industrial structure. The complexity and urgency of post-earthquake rescue tasks have also made drones a pivotal force in post-disaster emergency response. Due to many restrictions such as complex environmental terrain, obstacles, and climatic conditions after the disaster, rescue means and measures cannot complete the rescue task quickly, efficiently and perfectly. Due to its high flexibility, strong operability, and no need to touch the ground, drones have been widely used in the post-earthquake environment. As one of the key technologies of UAV technology, UAV path planning has an important impact on the effectiveness and speed of UAV post-disaster rescue missions. In the ever-changing environment of the disaster area, UAV path planning issues face many difficulties, such as obstacle avoidance, adaptation to complex terrain, and coping with changeable meteorological conditions during UAV planning flight. The traditional path planning algorithm can achieve good results, but the effect is not ideal in the low-altitude post-disaster emergency response in the dynamic changing environment. Therefore, in the low-altitude UAV environment, the optimal flight path is planned in the complex environment after the earthquake to ensure that the implementation of rescue missions has become an urgent problem to be solved.

The purpose of this study is to explore how to improve the efficiency and effectiveness of post-earthquake rescue through UAV path planning technology by combining the background of low-altitude economy and the needs of post-earthquake rescue. By analyzing the challenges in the post-earthquake environment and the advantages of UAVs, we design intelligent path planning algorithms that adapt to complex environments, promote the deep integration of low-altitude economy and post-disaster rescue, and hope to provide technical support for future post-disaster emergency response and the sustainable development of low-altitude economy.

2. The Rise of the Low-Altitude Economy and the Promotion of Drone Technology After the Disaster

2.1. The Concept and Industrial Chain of Low-Altitude Economy

In the past 10 years, with the trend of full electrification and intelligence of aircraft, developed countries have been committed to innovation and development in related aspects[1]. Taking the United States as an example, a series of promotion and reform bills have been introduced in the military and civilian fields. Among them, the U.S. Air Force's "Agility First" Program Tender Invitation released in 2020 is a particularly iconic event [2]. Urban air traffic system (UAM), advanced air mobility (AAM), rural air traffic (RAM), and regional air mobility (RUM) are the future models and trends of air transportation, so NASA has upgraded the low-altitude economy from the technical and system level to the low-altitude economy policy and system, and launched the low-altitude transportation mode policy, regulation and application technology for the development of low-altitude aircraft in the field of aircraft[4]. Similarly, countries such as Europe, Japan, and South Korea have issued corresponding policies and implementation outlines. This is enough to prove that the development of the low-altitude economy has risen to a new level[3].

At this stage, the development of strategic emerging industries represented by the low-altitude economy has become an important development direction for our country. On February 22, 2021, the "Outline of the Strategic Plan for the Optimization of the National Comprehensive Three-dimensional Transportation Network" was promulgated by the Central Committee of the Communist Party of China and the State Council, which is the first document to propose a "low-altitude economy" in the overall development plan[4]. After the subsequent 2023 Central Economic Work Conference established it as a strategic industry and strengthened policy support, it quickly showed an explosive development trend. By the end of 2024, more than 27 provinces, municipalities and autonomous regions (excluding Hong Kong) have clarified in their industrial plans related to the "low-altitude economy". It is not difficult to see that "low-altitude chasing" or "space racing" has been carried out in an all-round coverage of policy implementation[5].

Table 1. National civil aviation passenger turnover growth table

year	Growth rate of civil aviation passenger turnover (%)	Growth rate of civil aviation passenger turnover - domestic routes (%)
2020	-46.1	-31.1
2021	3.5	9.7
2022	-40.1	--
2023	163.4	138.6

With the inevitable trend of rapid development of low-altitude economy, technological progress represented by unmanned aerial vehicles provides the main driving force for

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adjusting the industrial structure and innovating production models[6]. As the main entity and equipment applied in urban low-altitude economy, low-altitude logistics and distribution, environmental monitoring, and agricultural UAV flight defense operations, UAV has become the main technology for the development of low-altitude economy due to its own characteristics of efficiency, speed and intelligence[7]. On the one hand, drones have unique advantages in promoting the optimization of low-altitude logistics chain structure and innovative distribution models in carrying out low-altitude logistics services and distribution, improving air travel and logistics efficiency, and reducing the risk of air transport links [8]. On the other hand, UAV low-altitude airspace activities are more convenient and flexible, which can reduce the safety risks of low-altitude airspace and improve the efficiency of low-altitude utilization through autonomous monitoring, analysis and decision-making[9]. In addition, under the integration and collaboration of UAVs and 5G communications, artificial intelligence, and edge computing, UAVs can be deeply integrated with smart low-altitude networks to realize the integration of low-altitude "air-ground-cloud", and can achieve "fully intelligent" management and services on the basis of ensuring autonomous trajectory navigation, autonomous collision avoidance, and remote visual control [10].

2.2. The Promotion of Drone Technology After the Disaster

In the research field of UAV rescue path planning, scholars at home and abroad have done a lot of research, especially in the post-disaster UAV assistance and rescue in various complex environments, which is a necessity that cannot be ignored. In the field of UAV application in emergency rescue, the FAA has carried out a variety of research work, conducted a more detailed in-depth study on the emergency avoidance technology that needs to be solved urgently in the application of UAV, and developed a complete UAV multi-factor performance evaluation system, which effectively guarantees and enhances the ability of UAV to avoid danger and escape in complex environments[11]; The European Air Traffic Authority (Eurocontrol) has made a breakthrough in the field of UAV collaborative technology, with the help of some new computing methods, so that UAVs can be combined into an efficient UAV system for optimal deployment and collaborative operation, thus making up for the shortcomings of a single UAV in the rescue mission in the disaster area[12].

In UAV track planning, Mohammadreza Radmanesh et al[13]A path planning algorithm based on a hybrid integer linear model is proposed, and a new path planning method is proposed for the problems of space-time limitation, obstacle avoidance and flight time optimization. Hoang et al[14]The scholars used the angular coding group optimization algorithm to analyze the path planning of multiple UAV formations to complete infrastructure inspection tasks, focusing on the efficiency and safety of the formation flight shape, and proposed an objective function that can optimize flight time and flight energy consumption, so as to improve the operation rate and ensure flight safety.Hamid et al[15]In view of the complex environment after the disaster, a multi-factor path allocation algorithm is proposed, which comprehensively considers factors such as topography, meteorological factors and UAV performance, which improves the adaptability and effectiveness of rescue missions.

The work in China has also achieved good results. The China Earthquake Administration has carried out research on the development of unmanned aerial vehicle emergency command system in the "12th Five-Year Plan", realizing rapid airspace reconnaissance and data capture in the emergency response to natural disasters such as earthquakes, and providing effective intelligence for disaster area rescue work[16]. The National Natural Science Foundation of China has carried out a series of projects related to UAV path planning, which has promoted the development of UAV autonomous flight and emergency planning path technology[17].

In terms of trajectory planning, Beihang University uses deep learning technology to propose UAV route planning that can quickly perceive and respond to unknown environments, improving the obstacle avoidance efficiency of path planning[18]. Tsinghua University has optimized the trajectory planning in complex environments through multi-source data fusion technology, improved the technical performance of trajectory planning, and enhanced the safety of UAVs. With the development of information technology and Internet of Things technology, real-time data processing and communication technology have played an important supporting role in UAV path planning[19]. China Electronics Technology Corporation and others have made technological innovations in UAV communication data links and fleet collaborative control to improve the collaborative efficiency of UAV fleets at disaster sites[20].

Nanjing University of Aeronautics and Astronautics proposed an artificial potential field method based on dynamic adjustment parameters to realize real-time calculation of search and rescue paths[21]; Harbin Institute of Technology combines genetic algorithm and ant colony algorithm to propose a heuristic search strategy, which reduces the search time and complexity and provides a new solution for rapid search and rescue of emergency rescue[22].

3. Technical Application of Drones After the Earthquake

3.1. UAV Reconnaissance and Data Processing

UAV reconnaissance and data processing the first major thing that UAV technology can do in the disaster area is to bring great convenience to the rescue work after the earthquake through UAV detection and data processing. In the complex and unpredictable situation of the earthquake, it is difficult for traditional post-earthquake rescue to make real-time, effective and accurate information processing, and advanced drones, such as multi-rotor drones using GIS, three-dimensional modeling and other technologies, will bring great convenience in post-earthquake rescue[23].

The application of 3D geographic modeling technology completes the generation of 3D digital models of the disaster area after the disaster, so that decision-makers can understand the terrain conditions in the disaster area in real time (such as house damage, the number of casualties, walkable roads, etc.) and formulate reasonable and effective rescue plans in a short period of time[24].

Combined with UAV video transmission and 3D geographic information, real-time monitoring technology after disasters is realized. The video transmission and positioning technology of the 3D map of the UAV can quickly and accurately plan the reasonable rescue path and rescue distance for the command center, simulate and analyze the post-disaster scene, and improve the scientificity, rationality and accuracy of the command center's rescue decisions[25].

It is equipped with infrared thermal imagers, environmental perception equipment, etc., which further increases the accuracy of search and rescue. After the earthquake, a large number of disaster areas may be prohibited from entering directly due to rubble, fire, etc., and there are blind spots in conventional search and rescue equipment. The drone detects the fire situation through infrared imaging, and can analyze the development trend of the flame, find the thermal imaging characteristics of the trapped person, and provide important information to rescuers[26].For example, for the reconnaissance of special fires such as toxic substance leaks, drones equipped with gas sensors and temperature sensors can realize real-time monitoring of dangerous areas, ensure the safety of search and rescue team members and provide important real-time information[27].

Furthermore, the effective research and development of multi-intelligent UAV coordinated operations and intelligent dispatch systems will greatly enhance rescue efficiency and dispatch efficiency. Through the coordinated operation of multiple groups of drones, rescue tasks can be completed quickly and efficiently, ensuring the timeliness of rescue work [28].

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Table 2. The functional use of the UAV system in post-earthquake rescue

Key technologies	Specific functions and their uses
3D geographic modeling system	By taking images of the disaster area, drones generate a three-dimensional digital model to help the command center understand the overall situation of the disaster area, such as damage to buildings, road obstacles, etc., and provide accurate data for follow-up rescue
Real-time video surveillance system	The real-time video transmission function of drones allows the command center to grasp the dynamics of the disaster area in real time, analyze the disaster situation and make decisions, and improve the timeliness and accuracy of rescue response
Infrared thermal imaging system	Infrared thermal imaging technology helps drones detect the heat signatures of fire sources and trapped people from the air, especially in rubble or smoky areas, and can accurately locate trapped people and fire sources
Environmental monitoring system	UAVs can be equipped with gas sensors and other equipment to monitor the air quality, gas concentration and temperature in the disaster area, detect toxic gas leaks or explosion hazards in a timely manner, and ensure the safety of rescuers
Multi-machine collaborative operation system	Multiple drones work together to perform different tasks, improving rescue efficiency. Through the intelligent scheduling system, the efficiency of task allocation and execution is ensured
Intelligent scheduling system	Through the analysis of real-time UAV data, the intelligent dispatch system can dynamically adjust task allocation and routes, improving the flexibility of rescue operations and the ability to respond to changes

3.2. Drone Search and Rescue and Material Delivery

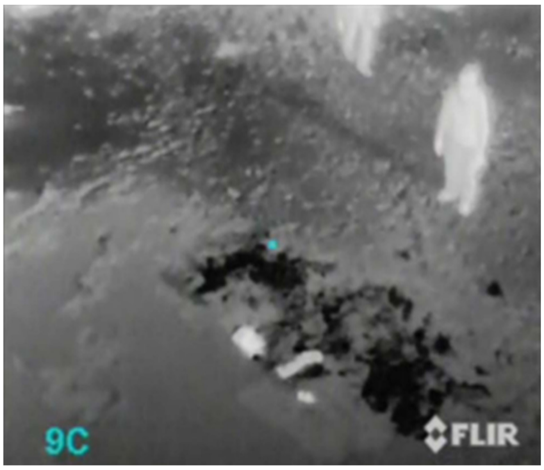

Fig 1. The exposed part of the head, arms, and knees at the bottom of the image captured by the infrared camera is clearly visible

UAV search and rescue UAV search and rescue technology has played a role in post-earthquake search and rescue, and has increasingly become one of the key technologies in disaster rescue, especially in post-earthquake rescue after sudden natural disasters such as earthquakes[29].With the help of UAV telemetry and remote sensing, fixed self-navigation, efficient data processing and other characteristics, search and rescue personnel can quickly and accurately carry out search and rescue work in disaster dangers and hard-to-reach places, greatly improve search and rescue efficiency, reduce search and rescue costs and casualties[30].The technical contribution of UAVs in post-earthquake search and rescue is mainly reflected in the following aspects:

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For example, combined with high-resolution cameras and thermal imaging technology, drones can quickly take pictures and scan over the disaster site to find the location of trapped people, especially in the area of collapsed buildings after the earthquake [31].

From the image taken by the red camera in Figure 1, it can be seen that the exposed parts such as the head and neck, arms, and knees of the human body at the bottom are very clear under the red camera. Therefore, the use of various sensors and equipment carried by drones can effectively expand their use in post-disaster search and rescue. Against the background of aftershocks and secondary disasters that may exist after an earthquake, UAVs monitor changes in the disaster area environment in real time, such as ground movement and meteorological changes, providing important auxiliary information [32]. The automatic positioning and navigation system equipped with some UAVs can automatically generate flight routes according to preset search tasks, reducing the manpower operation process and increasing search efficiency.

In complex terrain or areas with heavy damage, the lives of traditional rescuers are at greater risk. The application of drones basically avoids the risk of rescuers being directly exposed to secondary disasters. The autonomous flight of the UAV itself and the intelligent identification system can completely enable search and rescue operations to be completed without ground command, thereby improving the rescue rate and the survival rate of rescuers. UAVs have the advantages of rapid deployment and recovery, and can be placed in the disaster area in the shortest time to complete the accurate positioning and monitoring of personnel, and provide relevant effective basis in the rescue and treatment of post-disaster personnel.

3.3. Drone Material Delivery

UAV Rescue Material Delivery UAV Delivery of Post-disaster Relief Materials has shown its technical characteristics and application value after the earthquake, first, the use of the characteristics of UAV aerial flight to break through the impact of traffic road obstruction in the post-earthquake disaster area to the traffic, can enable the transportation materials to be delivered to the location of post-earthquake rescue personnel as soon as possible, and accelerate the efficiency of earthquake disaster relief. After the occurrence of earthquakes, floods and other disasters, the use of traditional means for rescue will be subject to various restrictions such as traffic damage and road congestion, and drone rescue due to the ability to fly in the air, for the destroyed road can be crossed freely, and the materials will be transported to the destination in the shortest time, after the 2015 Nepal earthquake, the traffic in the disaster area has been completely paralyzed, the traditional rescue methods are blocked, the use of drone delivery can carry medical medicines, food and water, through air rescue rapid feedback, The adverse effects of traffic jams are avoided[33].The precise navigation technology carried by the UAV combined with intelligent control technology makes the UAV more accurate in delivering materials, which can ensure the accurate positioning and smooth delivery of materials to the disaster area, and avoid the phenomenon of waste of material delivery to the greatest extent. The satellite positioning system carried by the UAV combined with the ground-to-air monitoring system can enable the UAV to accurately locate and effectively deliver relief materials to the affected people in the disaster area, especially in the ruins area after the earthquake, rescuers can quickly locate the affected personnel according to the instructions and implement the delivery, which greatly reduces the probability of misdelivery or loss[34].Second, the use of drones can minimize casualties in earthquake disaster rescue. With the continuous development of the disaster situation, especially when high-rise buildings collapse and mudslides, rescuers will face the risk of serious injury to themselves. Drones can replace manual entry into dangerous areas, ensuring the safety of rescuers and reducing the risk of loss of personnel[35].During the 2016 earthquake relief in central Italy, drones were used to monitor the safety of houses and the stability of buildings after the disaster to ensure

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the safety of rescuers and to be able to carry out rescue work in safer areas[36].At the same time, drones can also upload real-life photos and related data to the disaster rescue headquarters in a timely manner, providing real-time feedback to the rescue headquarters and assisting decision-making and command. The drone can carry high-definition cameras, thermal imaging, etc., which can be used to investigate the disaster area as a whole, and provide detailed information on the ground and the distribution of victims in a timely manner, so that the command center can quickly adjust the rescue plan[37].

The advantages and disadvantages of drones in post-earthquake rescue. There are still technical and application challenges in the application of UAV post-earthquake rescue. The problem of UAV load and endurance will be an obstacle in the promotion of UAV post-earthquake rescue applications, especially for large-scale earthquake relief. The application of drones to transport materials after earthquakes is limited in a single load, and the flight endurance is also limited[38]. During the rescue of the 2017 Mexico earthquake, although the drone successfully carried out aerial reconnaissance and some material delivery, due to load constraints, it was not possible to complete the delivery of large-scale supplies in a single time, resulting in the need to return to charge and load multiple times[39].

Airspace management and regulatory issues remain a major obstacle to the widespread adoption of drones. In post-earthquake emergency rescue, traditional aviation management systems may not be able to effectively cover the flight needs of drones. There may be multiple drones performing tasks at the same time in the disaster area, and how to coordinate the airspace and avoid flight conflicts between drones and other aircraft has become an urgent problem to be solved. The existing airspace management system lacks a flexible adjustment mechanism for post-disaster emergencies, which requires relevant departments to preset airspace management strategies in disaster response plans to ensure the efficient operation of drones[40]. Although drones are technically highly automated, their operation still requires professional support. Infrastructure in post-earthquake areas is often severely damaged, communication and navigation facilities are damaged, which can affect drone operations, and the shortage of professional operators is also a factor limiting drone adoption[41]. Therefore, in order to improve the application effect of UAVs in post-earthquake rescue, it is necessary to further improve and optimize the technology, management and operation.

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4. Modeling and Analysis of Search Routes in Rescue

In this paper, the problem of anti-radiation UAV search route planning mainly includes constraints, cost indicators and other elements, which can generally be described as follows: in the designated search area, the improved method is used to plan a closed route that meets a series of constraints to make the route planning cost index ("field of view coverage") the greatest, so that the target is within the search field of view of the UAV seeker as much as possible. The anti-radiation UAV runway-shaped search route consists of two semicircular arcs with a radius of r and two parallel straight routes with a length of x, as shown in Fig. 2.

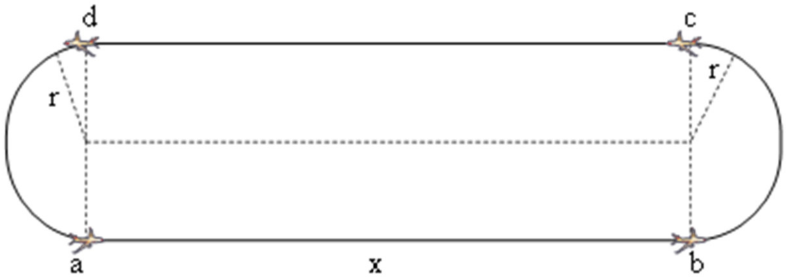

Fig 2. Anti-radiation UAV runway-shaped search route

Since only the target radar is within the field of view of the anti-radiation UAV seeker is the prerequisite for effective search suppression, the search route optimization in this paper only considers the needs of the UAV rescue mission, that is, the field of view coverage of the UAV seeker to the target radar.

When considering the pitch field of view constraints, the pitch coverage angle in the vertical direction is β , and it can be seen that:

$$\beta_{\min} \leq \beta \leq \beta_{\max} \tag{1}$$

When considering the horizontal field of view constraints, the horizontal coverage angle in the horizontal direction is known as ϕ :

$$\phi \leq \phi_o \tag{2}$$

Equation (1)~(2) is the field of view coverage criterion of the seeker. The following is based on the modeling of equations (1)~(2) to analyze the field of view coverage of the traditional search routes in the two countries.

Explain the field of view coverage based on the coverage area:

Define "field of view" W to indicate the coverage of the field of view of the UAV on the search route, and measure the search suppression effect of the search route on the target radar:

$$W = \sum_{i=1}^{N} S(i) / \sum_{j=1}^{M} S(j) \tag{3}$$

Thereinto:

M: Represents the total number of navigation sections in the planned search route;

N: represents the number of target radar flight segments covered by the seeker's field of view, and the flight section is the line segment composed of two adjacent voyage points in the route;

Through learning, we have a preliminary understanding of the UAV search route, which is mainly "8" and "runway". After a comprehensive analysis of the two search routes, in view of the advantages of the "runway" route, such as high field of view coverage, high mission efficiency, and strong adaptability to terrain and obstacles in complex environments, this paper mainly studies the "runway" search route.

Combined with Figure 3, when the UAV flies at point O, the instantaneous field of view coverage of the seeker is trapezoidal ABCD.

In ΔOHF , it can be known from the tangent theorem:

$$HF = OH \cdot \tan \beta_{\min} = H \cdot \tan \beta_{\min} \tag{4}$$

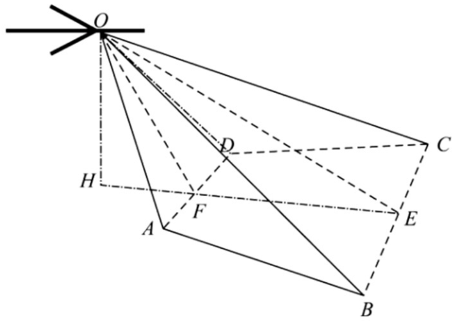

Fig 3. The field of view coverage of an anti-radiation UAV at a certain time

In the same way, in ΔOHE the middle, it can be known from the tangent theorem:

$$HE = OH \cdot \tan \beta_{\max} = H \cdot \tan \beta_{\max} \tag{5}$$

$$\therefore FE = HE - HF = H \cdot \left(\tan \beta_{\max} - \tan \beta_{\min} \right) \tag{6}$$

ΔOHF and then obtained by the cosine theorem:

$$OF = \frac{OH}{\cos \beta_{\min}} = \frac{H}{\cos \beta_{\min}} \tag{7}$$

From the relationship of the angles, it can be known:

$$\angle OFA = \angle OFD = 90^{\circ} \tag{8}$$

In Δ OF, it can be known from the Pythagorean theorem

$$AF = \frac{\sqrt{3}}{3} OF \tag{9}$$

By substituting (9) from symmetry, we get:

$$AD = 2AF = \frac{2\sqrt{3}}{3} OF = \frac{\frac{2}{3}\sqrt{3}H}{\cos \beta_{\min}} \tag{10}$$

Combined with Fig. 3, it can be seen that AD is the closest end covered by the UAV seeker when the pitch is maximized, while BC is the farthest end of the UAV seeker with the smallest pitch.

Combined with the previous research, a schematic diagram of the field of view coverage of the passive seeker when flying on the runway search route of the anti-radiation UAV can be obtained as follows

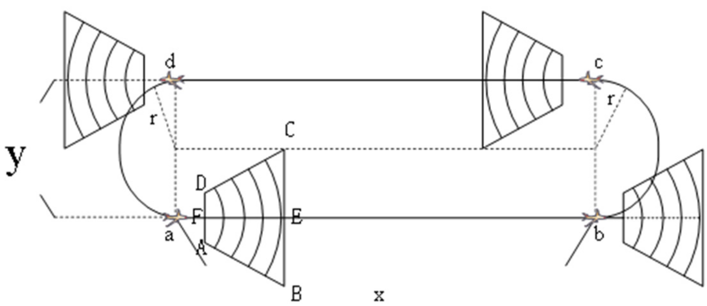

Fig 4. The field of view coverage of the drone when flying at a certain position

By integrating the field of view coverage of the UAV in each instantaneous time of the complete route in Figure 4, we can get the result:

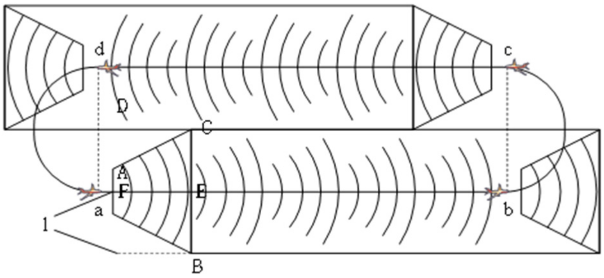

Fig 5. Field of view coverage of the drone along the entire route

5. Conclusion

With its application in key technologies of emergency rescue, UAVs have shown the advantages of high safety, strong environmental adaptability and rich functions, bringing new ideas and methods to emergency rescue work. In terms of route planning, the route planning with target optimization as the strategy, especially the in-depth modeling analysis of the "runway-shaped" search route and the optimization under different conditions, combined with the simulation results, it can be seen that the flight altitude, the length of the level flight section and the turning radius of the route have an important impact on the field of view coverage of the UAV. This provides a theoretical basis for the efficient use of drones in actual emergency rescue. However, despite the obvious advantages of drones in emergency rescue, it is still necessary to continuously improve technology to improve their reliability and intelligence in complex and changeable rescue environments, so as to better serve the emergency rescue cause, reduce disaster losses, and ensure the safety of people's lives and property.

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